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Available sources of antineutrinos exert macroscopic forces on such crystals as a result of elastic scattering. In this paper a chopper is described for modulating the antineutrino forces, in order to excite normal modes of elastic solids. Experiments are reported.

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CHOPPER FOR NEUTRINOS AND ANTINEUTRINOS

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October 31, 1989

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DEPARTMENT OF PHYSICS AND ASTRONOMY

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Chopper for Neutrinos and Antineutrinos

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Abstract

A new approach to weak interaction physics employs detectors which are nearly perfect single crystals, with high Debye temperatures. Total scattering cross sections are proportional to the square of the total number of quarks.

Available sources of antineutrinos exert macroscopic forces on such crystals as a result of elastic scattering. In this paper a chopper is described for modulating the antineutrino forces, in order to excite normal modes of elastic solids. Experiments are reported.

Introduction

Theory has been presented for coherent elastic scattering of very weakly interacting particles by quarks in nearly perfect[1,2] single crystals. Elastic scattering experiments were described[2], employing a torsion balance. An antineutrino source was cycled between small and large distances from the torsion balance. Repulsive forces were observed, consistent with large elastic scattering cross sections, proportional to the square of the number of quarks.

A torsion balance has a long period and responds to seismic vibrations. A harmonic oscillator with much shorter period may be employed, together with an antineutrino chopper, to modulate the incident particle flux at the frequency of the oscillator.

Fork Harmonic Oscillator

An aluminum tuning fork with normal mode frequency close to 87 hertz was employed, as shown in Figure 1. Lead zirconate titanate crystals provided electromagnetic coupling of the normal mode vibrations to a low noise amplifier. Theory predicts the equivalent circuit shown in Figure 2 for the spectral region near the normal mode frequency. Measured values of the parameters are given.

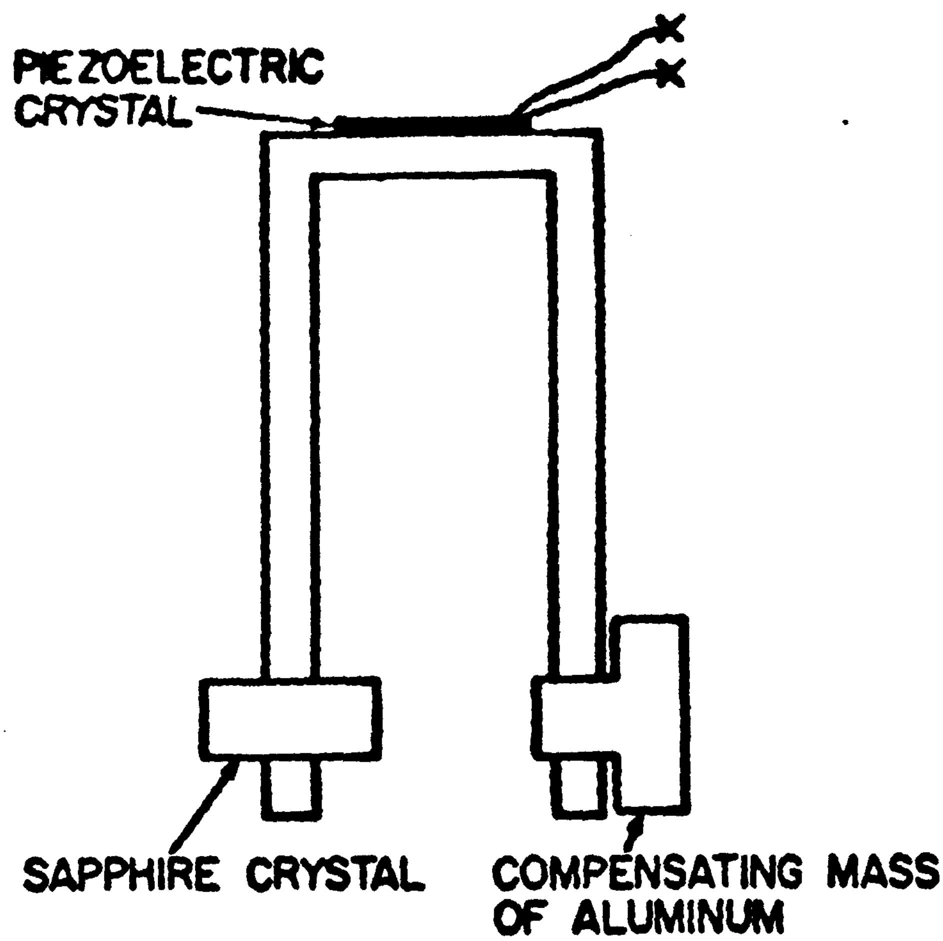
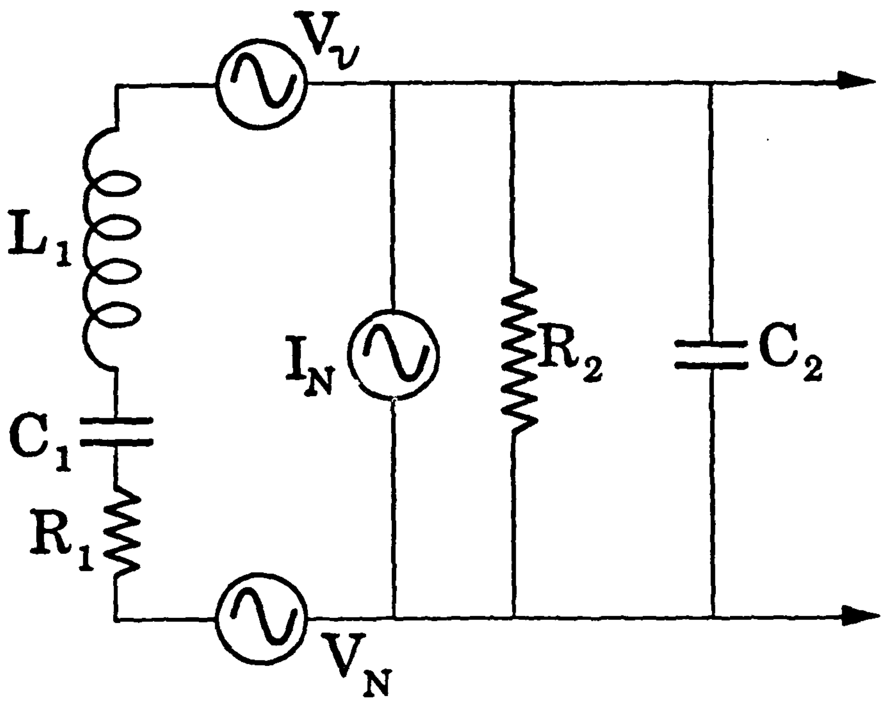

PIEZOELECTRIC
CRYSTAL
SAPPHIRE CRYSTAL
COMPENSATING MASS
OF ALUMINUM

Figure 1



$L_1 \;=\; 1.06 \times 10^5$ HENRIES

$C_1 \;=\; 31.5 \times 10^{-12}$ FARADS

$R_1 \;=\; 9361$ OHMS

$C_2 \;=\; 1.2 \times 10^{-7}$ FARADS

$R_2 \;=\; 1.9 \times 10^6$ OHMS

$\langle V_N^2 \rangle = 2kTR_1 \Delta\, \omega/\pi$

$\langle I_N{}^2 \rangle = 2kT\, \Delta\, \omega/\pi\, R_2$

$V_\nu \;=\; K\Phi\, f(N_T, Z_T, E_\nu, M, T_0)$

Figure 2

Chopper System

Three sapphire crystals, each 5 cms in diameter and 7.5 cms long, were mounted at 120 degree intervals between two circular aluminum discs. The crystal structure was rotated at 1/3 the fork normal mode frequency by a closed loop servosystem. The servosystem was designed to operate with time dependent potentials, with Fourier components far from the 87 hertz fork frequency, in order to avoid large control potentials at the fork normal mode frequency. A synthesizer was preset to a frequency N times the fork frequency. This serves as the reference. A circular disc with 3N alternate black and silver radial divisions was mounted on the rotating structure. An infrared source and sensor measured the rotation frequency of the crystals. This was compared with the frequency of the synthesizer. If the speed was too small, the servoamplifier increased power to the d.c. drive motor. If the speed was too large, the servosystem decreased the motor input power.

A second circular disc with 3 silver and 3 black sectors was mounted on the opposite side of the crystal structure. Another infrared source and sensor provided the required reference signal for synchronous detection of the fork output.

A second chopper was developed with six crystals and rotation frequency 1/6 of the fork normal mode frequency, with another servosystem to control the frequency of rotation to required tolerances.

The system was configured as shown in Figure 3

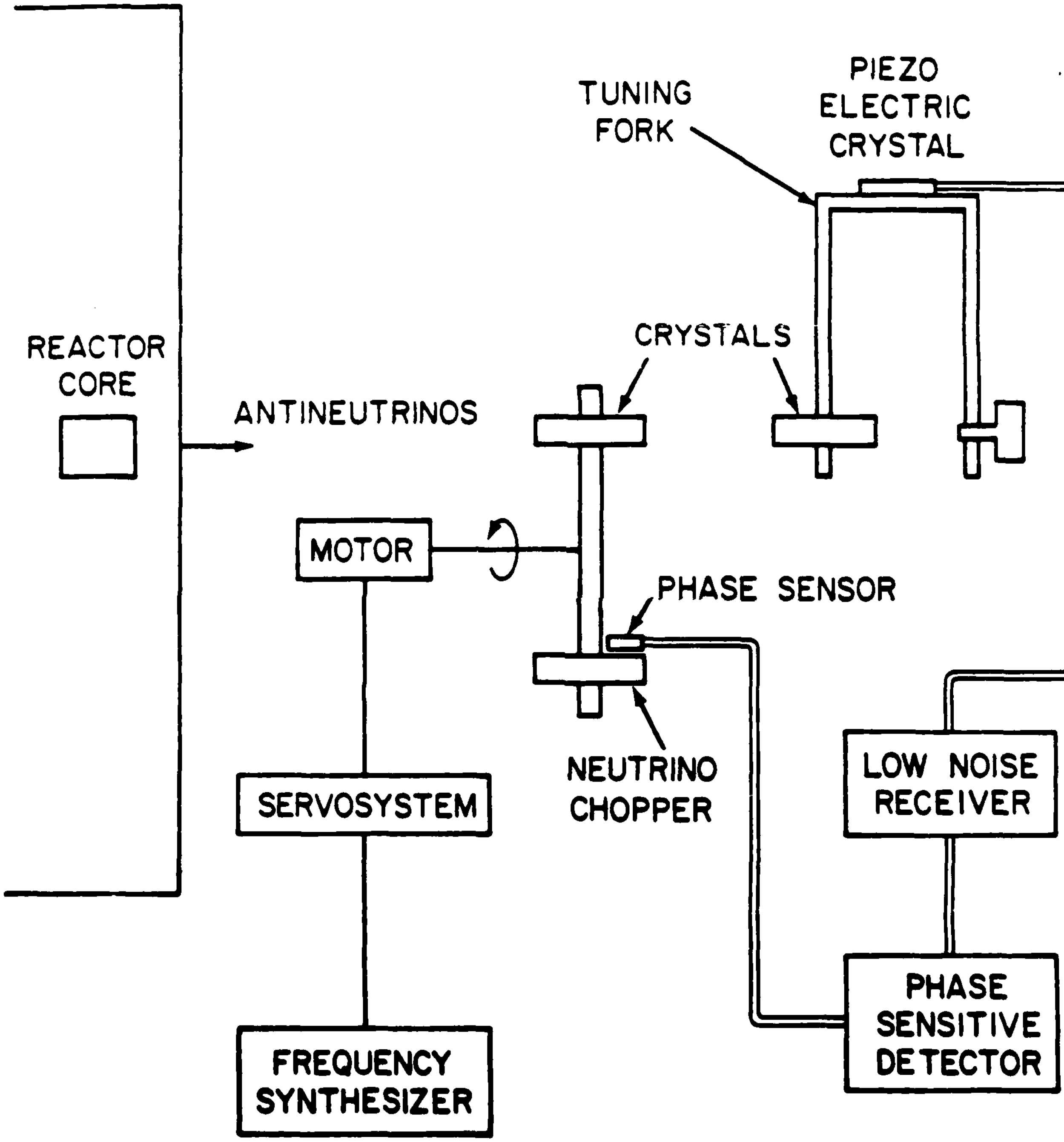

REACTOR
CORE
ANTINEUTRINOS
TUNING
FORK
PIEZO
ELECTRIC
CRYSTAL
CRYSTALS
MOTOR
PHASE SENSOR
NEUTRINO
CHOPPER
SERVOSYSTEM
LOW NOISE
RECEIVER
PHASE
SENSITIVE
DETECTOR
FREQUENCY
SYNTHESIZER

Figure 3

Circuits and Electronics

Figure 4 is the low noise pre amplifier circuit for the tuning fork. This is followed by a postamplifier and synchronous detector of conventional design.

Figure 5 is the circuit diagram of the servo amplifier which controls the chopper frequency.

Observations

The fork chopper system was operated at the United States National Bureau of Standards reactor. With reactor operating at 15 megawatts, a large output was observed, with fork chopper system 20 feet from the core center. When the reactor was switched off, the output of the fork did not immediately fall to a low value, but slowly decreased to 2 1/2 percent of the reactor on value, with a time scale of hours. This is consistent with the conclusion that antineutrinos from Beta decay products were being observed. The neutron and gamma ray backgrounds in the reactor vicinity became very small as soon as the reactor was switched off. Only the antineutrino output, controlled by the long period Beta decays, requires time scales of hours for decay.

To further check the hypothesis that antineutrinos were being observed, different kinds of scatterers were placed between chopper fork system and reactor.

Figure 6 shows a record of power with and without a large single crystal of silicon, placed in the line of sight between reactor and fork chopper. Smaller effects were observed with a large sapphire crystal. Sapphire has a Debye temperature of 1000 kelvin, while silicon has a Debye

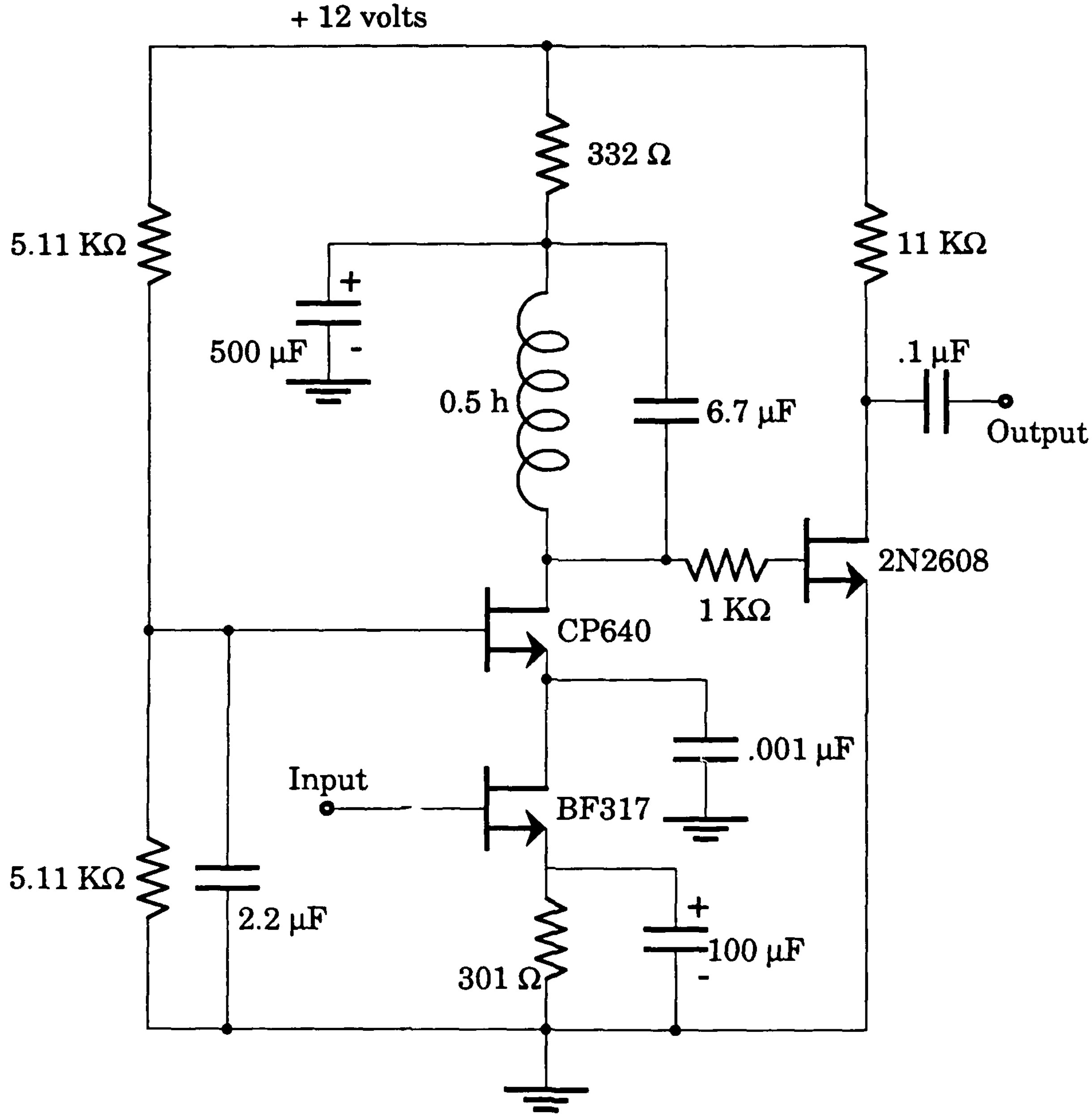
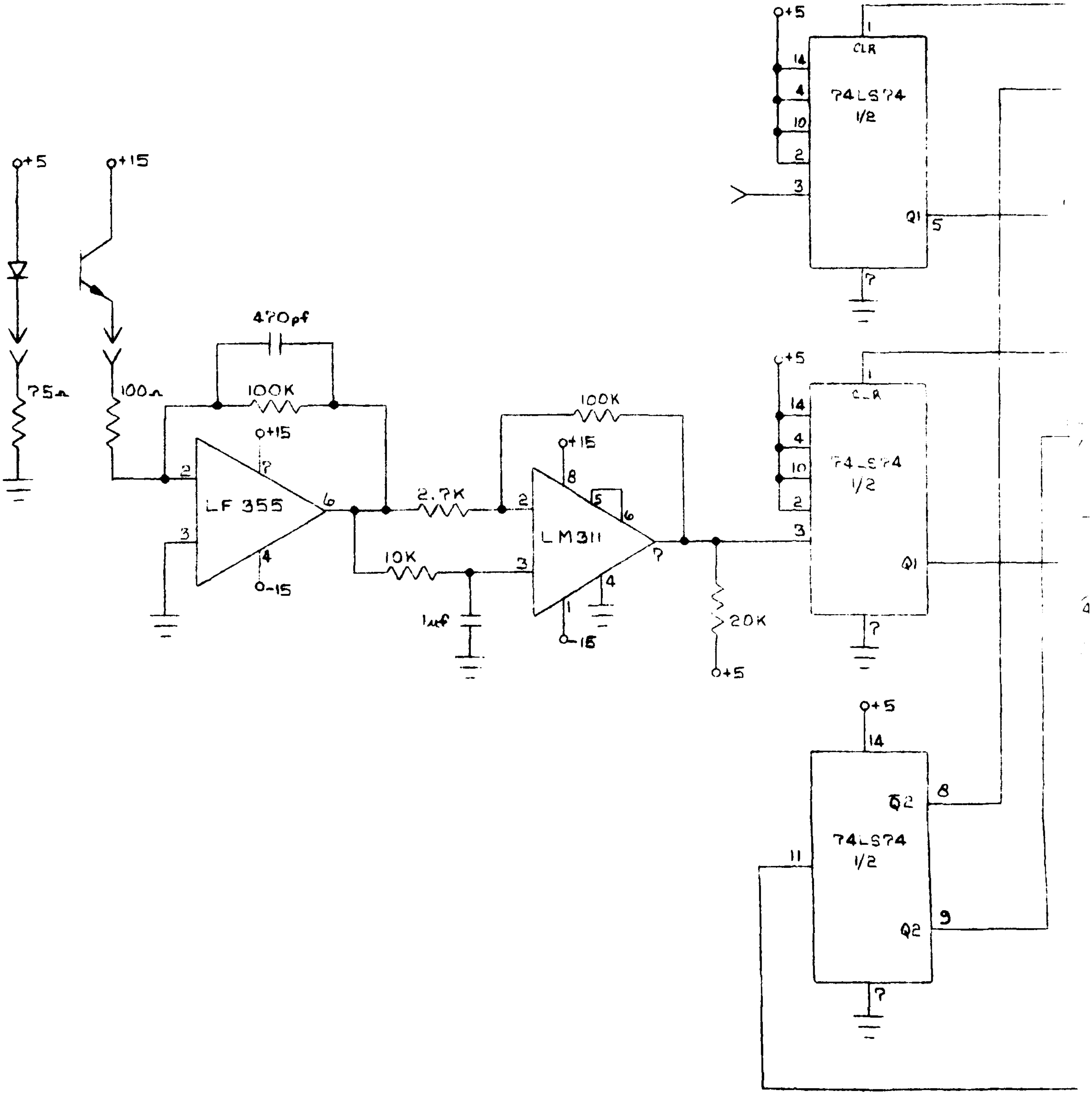
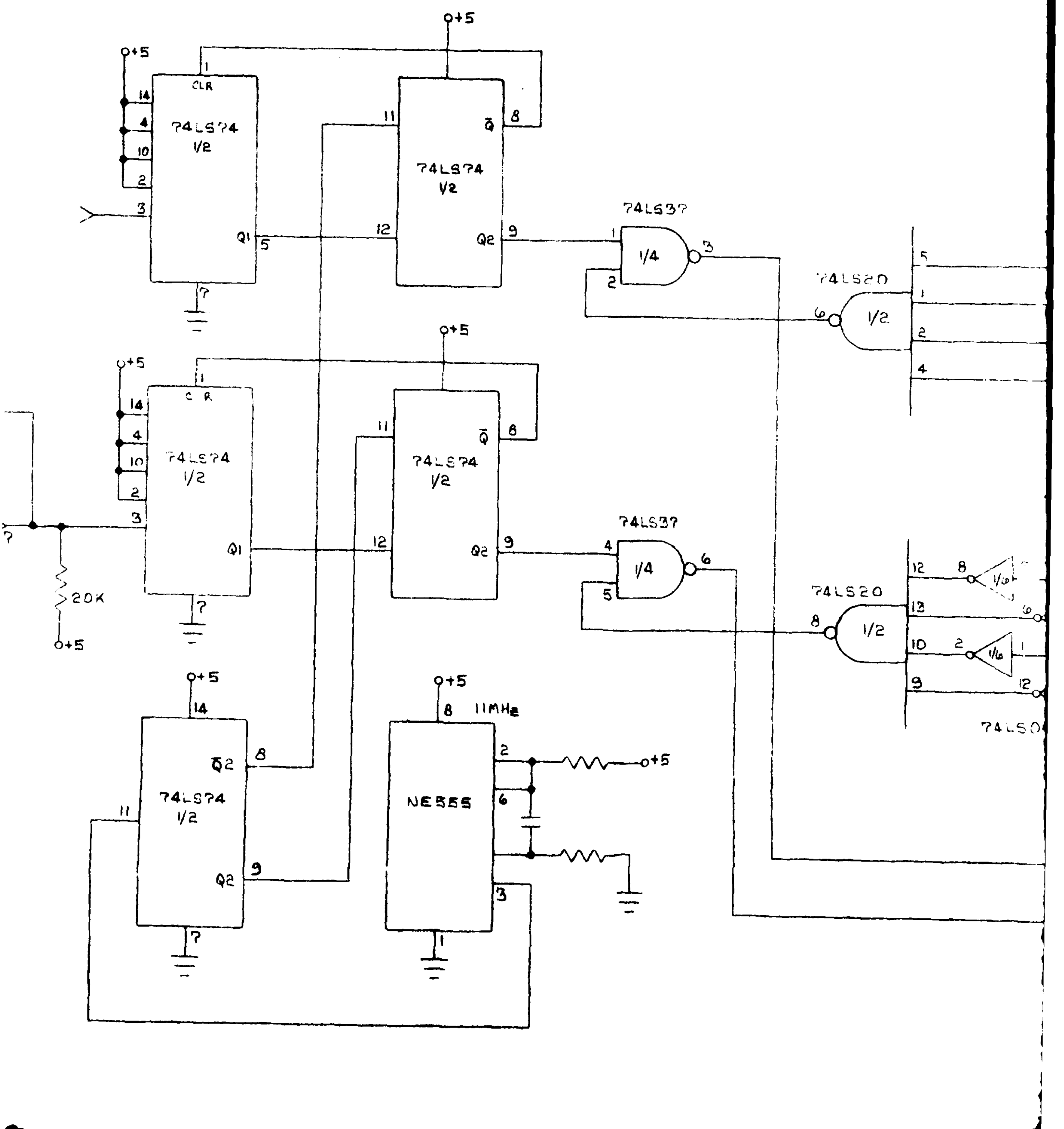
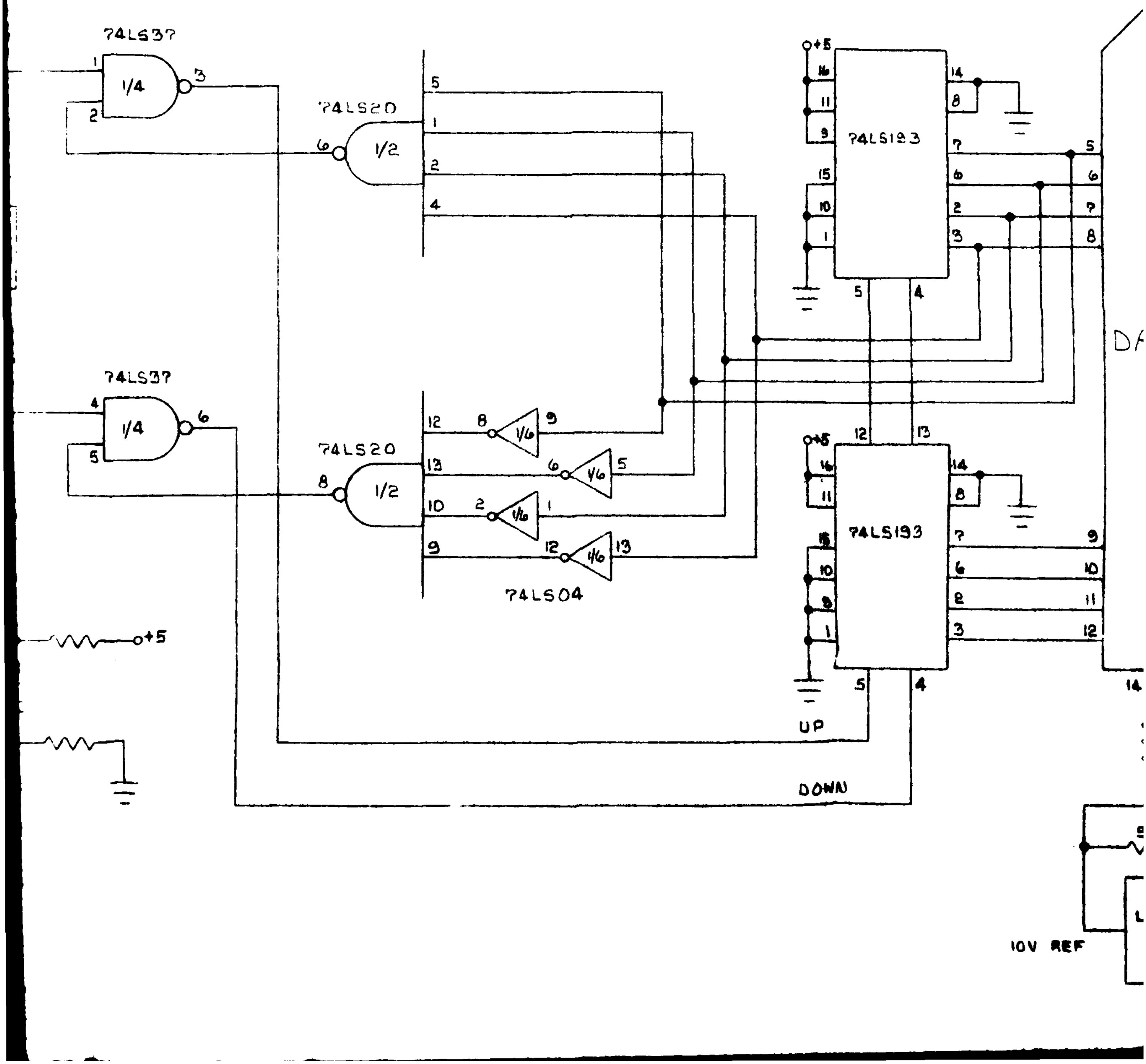

+ 12 volts
332 Ω
5.11 KΩ
11 KΩ
+
500 µF
-
.1 µF
0.5 h
6.7 µF
Output
2N2608
1 KΩ
CP640
.001 µF
Input
BF317
5.11 KΩ
2.2 µF
+
100 µF
-
301 Ω

Figure 4

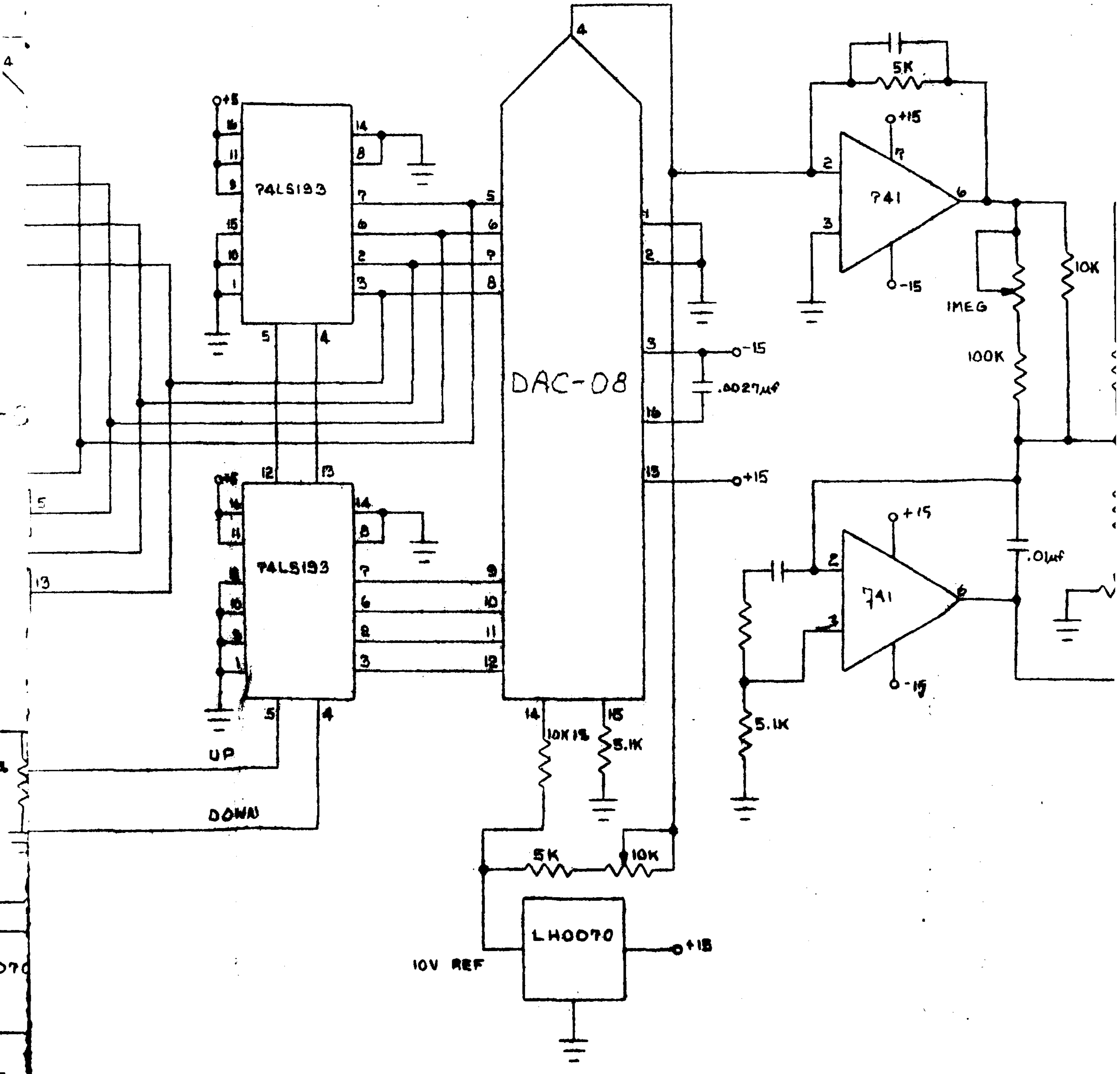


+5
+15
75Ω
100Ω
470pf
100K
LF 355
+15
-15
2.7K
10K
1uf
100K
LM311
+15
-15
20K
+5
74LS74
1/2
CLR
Q1
74LS74
1/2
CLR
Q1
74LS74
1/2
Q̄2
Q2

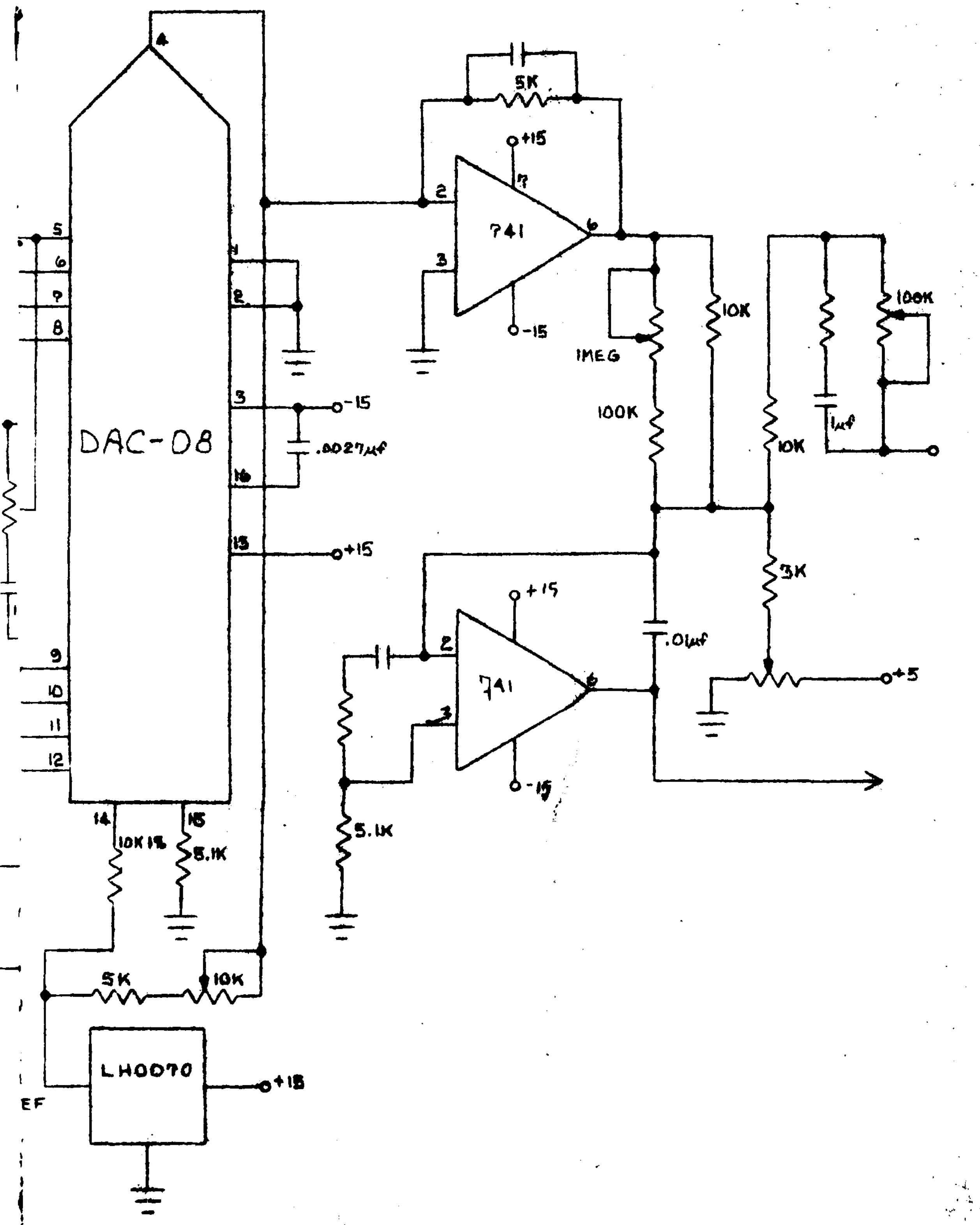

74LS74 1/2
CLR
74LS74 1/2
74LS37 1/4
74LS20 1/2
74LS74 1/2
74LS74 1/2
74LS37 1/4
74LS20 1/2
74LS74 1/2
NE555
11MHz
20K
+5
Q1
Q2
Q̄
Q̄2
1/6
74LS0



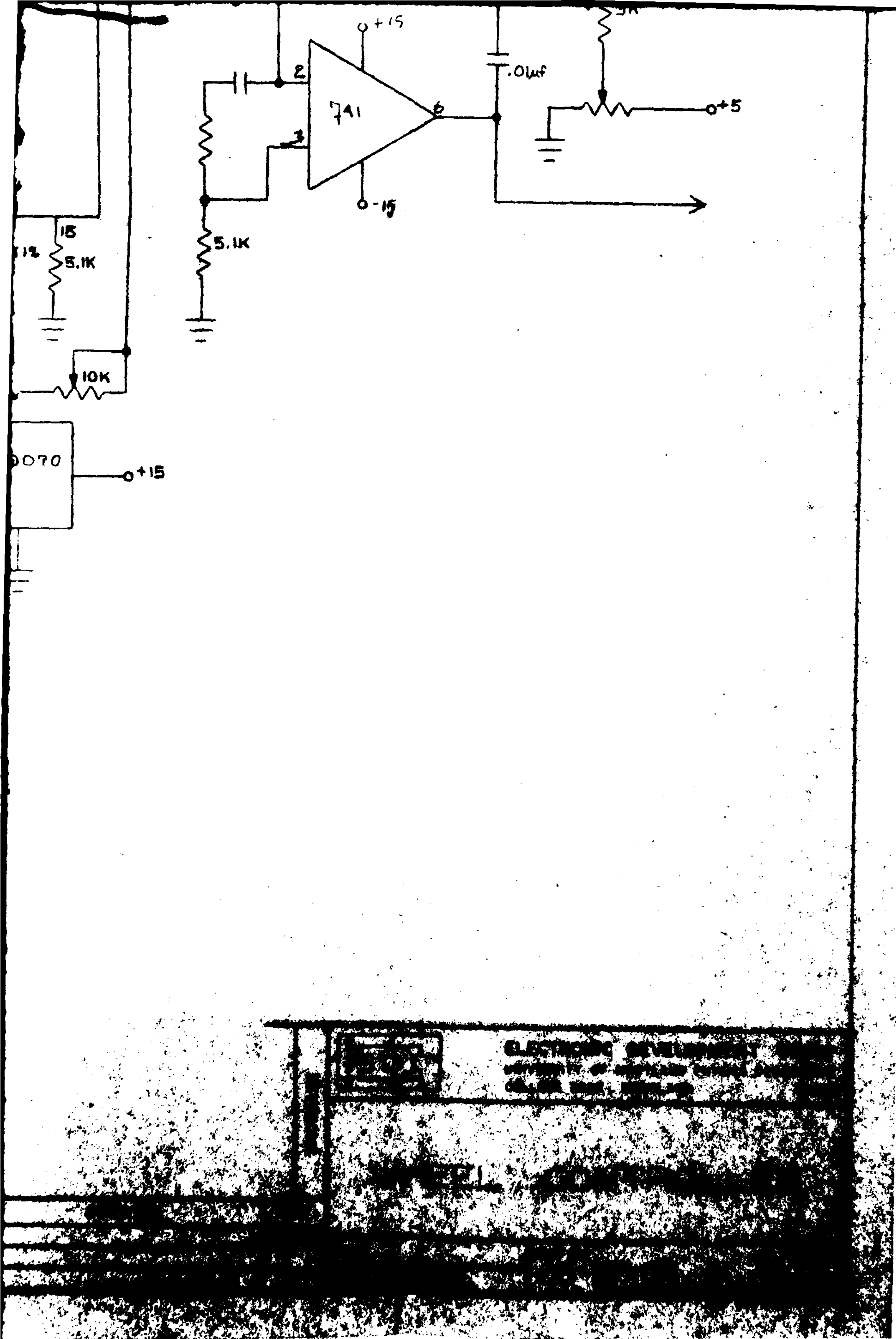
74LS37
1/4
74LS20
1/2
74LS193
DA
74LS37
1/4
74LS20
1/2
1/6
74LS04
74LS193
+5
UP
DOWN
10V REF



74LS193
74LS193
DAC-08
741
741
LH0070
5K
10K
IMEG
100K
.0027μf
.01μf
5.1K
10K 1%
5.1K
5K
10K
UP
DOWN
10V REF
+15
-15



DAC-08
741
741
5K
10K
1MEG
100K
100K
10K
1μf
3K
.01μf
.0027μf
+15
-15
+5
5.1K
10K 1%
5.1K
5K
10K
LH0070
+15
EF



+15
741
2
3
6
-15
.01µf
+5
5.1K
15
5.1K
10K
070
+15

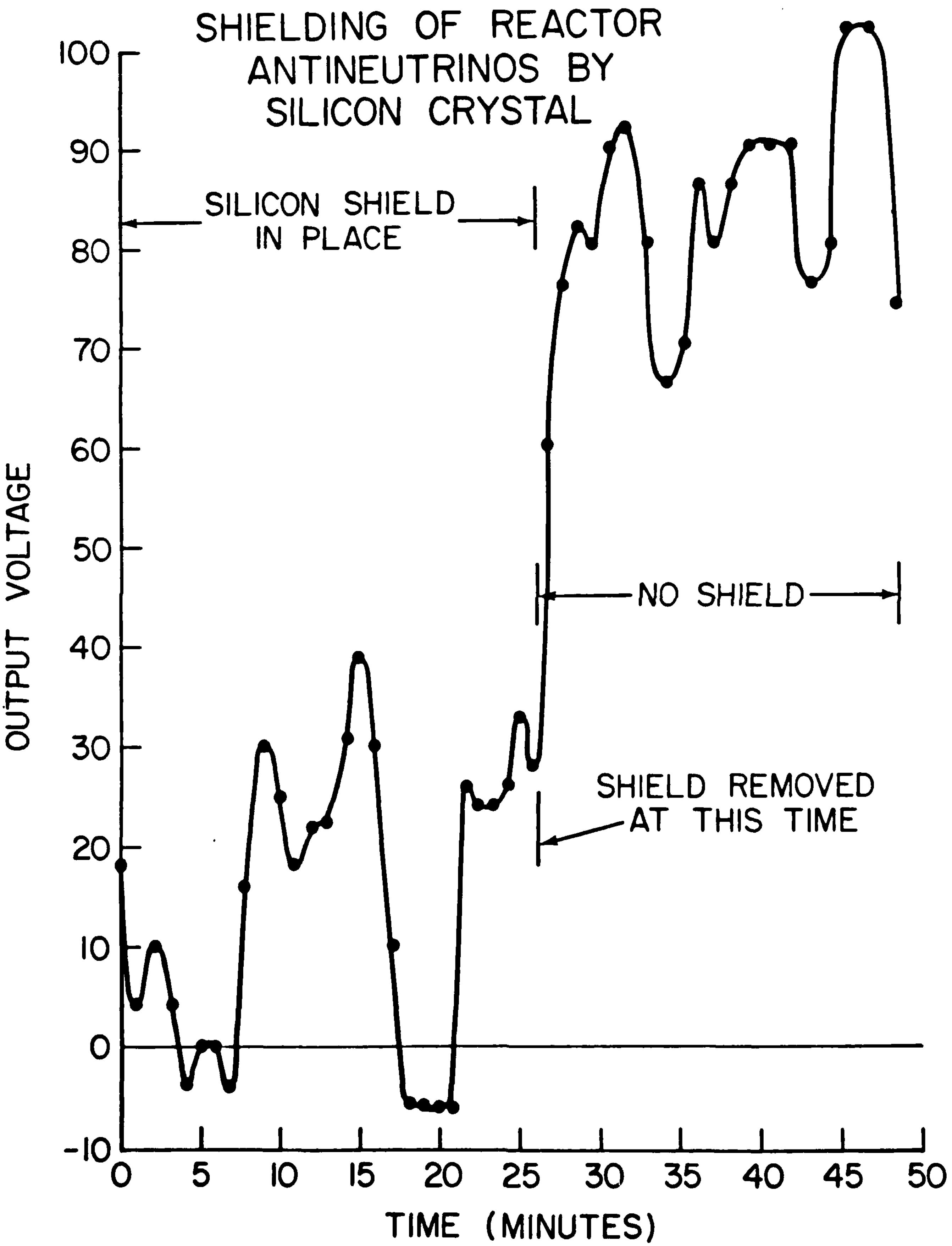

SHIELDING OF REACTOR
ANTINEUTRINOS BY
SILICON CRYSTAL
SILICON SHIELD
IN PLACE
NO SHIELD
SHIELD REMOVED
AT THIS TIME
OUTPUT VOLTAGE
TIME (MINUTES)
100
90
80
70
60
50
40
30
20
10
0
-10
0
5
10
15
20
25
30
35
40
45
50

Figure 6

temperature of 645 kelvin. If both crystals were free of dislocations, the sapphire would produce a larger effect than the silicon. We discussed this issue with Dr. R. DesLattes, an x-ray crystallographer at the U.S. National Bureau of Standards. Dr. DesLattes informed us that the large single sapphire crystal has large numbers of dislocations, approximately 100,000 per square centimeter. The silicon crystal has a much smaller number of dislocations and is therefore a superior scatterer for reactor antineutrinos with average energy 1.6 MeV. No significant reductions in fork output were observed when large polycrystalline materials such as lead or aluminum were placed between chopper fork system and reactor. No significant reduction in fork output was observed when powdered sapphire (aluminum oxide crystals) were placed between reactor and chopper fork systems.

All of these experiments were repeated when the reactor was switched off and sufficiently long time elapsed for Beta decay emission to decrease to background levels. No significant effects were observed with reactor off.

Observed Force with Reactor on.

The fork is a harmonic oscillator with mass m, mechanical resistance r and force constant k. The differential equation of motion is

$$m\frac{d^2x}{dt^2} + r\frac{dx}{dt} + kx = F$$

At resonance, $m\frac{d^2x}{dt^2} = -kx$ and

$$r\frac{dx}{dt} = i\omega r x = F$$

for harmonic fields.

With reactor off, $F \to o$, thermal, electronics, and seismic fluctuations imply a background temperature T_m given in terms of the displacement fluctuations by

$$\frac{1}{2} m \omega^2 \langle x^2 \rangle = \frac{1}{2} k T_m$$

Combining these equations gives fluctuations $\langle F_n^2 \rangle$,

$$\langle F_n^2 \rangle = r^2 \omega^2 \langle x^2 \rangle = \frac{r^2 k T_m}{m}$$

T_m is measured by observing the effect of a noise current generator coupled to the receiver input. Suppose switching the reactor on increases the power by a factor K_r. Then the reactor induced force F_r is given by

$$\langle F_r^2 \rangle = \frac{r^2 k K_r T_m}{m}$$

For these experiments T_m was 55,000 k and $F_r = 3.2 \pm 1 \times 10^{-5}$ dynes.

1. J. Weber Phys, Rev C 31, 1468 April 15, 1985

2. J. Weber Phys. Rev D 38, 1, pages 32-39, July 1, 1988.